

## HIGHER-ORDER MOMENT-BASED IMAGE PROJECTION METHOD AND IMAGE PROCESSING APPARATUS

### SUMMARY OF THE INVENTION

5       The present invention relates to a higher-order moment-based image projection method and an image processing apparatus, and more particularly to a higher-order moment-based image projection method and an image processing apparatus by which all data values along a projection axis are incorporated in a projection image produced from three-dimensional data.

10       One known image projection method for producing a projection image from three-dimensional data is the maximum intensity projection method.

      The maximum intensity projection method is an image projection method involving defining the maximum of three-dimensional data values along an axis perpendicular to a projection plane as the pixel value at the point of intersection  
15 of the axis and projection plane, and the method is used to display blood vessels in MRI (magnetic resonance imaging), X-ray CT (computed tomography), and ultrasonic diagnostic apparatuses (cf. "MEDICAL IMAGING DICTIONARY," published by Nikkei Medical Custom Publishing, Inc., sold by Nikkei BP Publishing Center, Inc.).

20       The maximum intensity projection method, however, poses the problem that only the maximum is incorporated in the projection image and other data values are not incorporated at all. Moreover, another problem is that information on whether the data has only one maximum point or a plurality of maximum points is not incorporated.

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### SUMMARY OF THE INVENTION

      It is therefore an object of the present invention to provide a higher-order moment-based image projection method and an image processing apparatus by which all data values along a projection axis are incorporated in the projection  
30 image.

In a first aspect, the present invention provides a higher-order moment-based image projection method, characterized in comprising: when projecting three-dimensional data onto a projection plane, determining a pixel value at a point of intersection of a projection axis and the projection plane based on:

$$P = \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i / n)^r \right|^{1/r},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ .

According to the higher-order moment-based image projection method in the first aspect, a pixel value on the projection plane is determined based on  $P$  as represented above, which  $P$  is a value obtained by removing  $V_i^r$  from  $(\sum V_i)^r$  and contains all  $V_i$ 's. Therefore, all values of the data  $V_i$  along the projection axis are incorporated in a projection image.

The reason why  $V_i^r$  is removed is to prevent one large data value from being dominant. For example, if there exist two data values  $V_1$  and  $V_2$  and  $r = 2$ , then  $(\sum V_i)^r = V_1^2 + 2 \cdot V_1 \cdot V_2 + V_2^2$ ; however, if  $V_1 \gg V_2$ , then  $(\sum V_i)^r \approx V_1^2$ , and  $V_2$  will not be incorporated. However, since  $(\sum V_i)^r - \sum V_i^r = 2 \cdot V_1 \cdot V_2$ ,  $V_2$  is incorporated even if  $V_1 \gg V_2$ .

If  $P = \sum V_i / n$  is used, it contains all  $V_i$ 's and it appears that all values of the data  $V_i$  along a projection axis may be incorporated in the projection image; however, in fact, one large data value is dominant. For example, if there exist two data values  $V_1$  and  $V_2$ , then  $\sum V_i = V_1 + V_2$ , whereas  $\sum V_i \approx V_1$  if  $V_1 \gg V_2$ , and hence,  $V_2$  will not be incorporated.

In a second aspect, the present invention provides a higher-order moment-based image projection method, characterized in comprising: when projecting three-dimensional data onto a projection plane, determining a pixel value  $G$  at a point of intersection of a projection axis and the projection plane as:

$$G = \left| \left( \sum_{i=1}^n Vi/n \right)^r - \sum_{i=1}^n (Vi/n)^r \right|^{1/r},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $Vi$ , and a real number greater than one is denoted by  $r$ .

- 5 The higher-order moment-based image projection method of the second aspect uses  $P$  in the higher-order moment-based image projection method of the first aspect as a pixel value  $G$  without modification.

In a third aspect, the present invention provides a higher-order moment-based image projection method, characterized in comprising:  
 10 determining a pixel value  $G$  at a point of intersection of a projection axis and a projection plane as:

$$G = \exp \left\{ \left| \left( \sum_{i=1}^n Vi/n \right)^r - \sum_{i=1}^n (Vi/n)^r \right|^{1/r} \right\},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $Vi$ , and a real number greater than one  
 15 is denoted by  $r$ .

The higher-order moment-based image projection method of the third aspect uses a value of an exponential function of  $P$  in the higher-order moment-based image projection method of the first aspect as a pixel value  $G$ .

In a fourth aspect, the present invention provides a higher-order  
 20 moment-based image projection method, characterized in comprising: when projecting three-dimensional data onto a projection plane, determining a pixel value at a point of intersection of a projection axis and the projection plane based on:

$$P = \left| \left( \sum_{i=1}^n Vi/n \right)^r - \sum_{i=1}^n (Vi^r)/n \right|^{1/r}$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ .

According to the higher-order moment-based image projection method of the fourth aspect, a pixel value on a projection plane is determined based on  $P$  as represented above, which  $P$  contains all  $V_i$ 's. Therefore, all values of the data  $V_i$  along a projection axis are incorporated in the projection image.

In a fifth aspect, the present invention provides a higher-order moment-based image projection method, characterized in comprising:  
10 determining a pixel value  $G$  at a point of intersection of a projection axis and a projection plane as:

$$G = \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i^r) / n \right|^{1/r},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one  
15 is denoted by  $r$ .

The higher-order moment-based image projection method of the fifth aspect uses  $P$  in the higher-order moment-based image projection method of the fourth aspect as a pixel value  $G$  without modification.

In a sixth aspect, the present invention provides a higher-order  
20 moment-based image projection method, characterized in comprising:  
determining a pixel value  $G$  at a point of intersection of a projection axis and a projection plane as:

$$G = \exp \left\{ \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i^r) / n \right|^{1/r} \right\},$$

where the number of three-dimensional data values along said projection axis is  
25 denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ .

The higher-order moment-based image projection method of the sixth aspect uses a value of an exponential function of  $P$  in the higher-order moment-based image projection method of the fourth aspect as a pixel value  $G$ .

In a seventh aspect, the present invention provides the higher-order  
5 moment-based image projection method having the aforementioned configuration, characterized in that:  $2 \leq r \leq 128$ .

According to the higher-order moment-based image projection method of the seventh aspect, since the contrast of a projection image varies with the order changing as  $r = 2, 3, 4, \dots$ , the order  $r$  may be selected such that a contrast  
10 conforming to the final purpose is attained. The contrast of the projection image is almost constant if the order becomes  $r = 128, 129, 130, \dots$ , and therefore, it is sufficient to provide an order up to  $r = 128$  in practice.

In an eighth aspect, the present invention provides the higher-order moment-based image projection method having the aforementioned  
15 configuration, characterized in that: an operator is allowed to change  $r$ .

In the higher-order moment-based image projection method of the eighth aspect, since the operator is allowed to change the order  $r$ , an order  $r$  that provides a contrast desired by the operator can be selected.

In a ninth aspect, the present invention provides an image processing  
20 apparatus characterized in comprising: three-dimensional data storage means for storing three-dimensional data; projection direction specifying means for use by an operator to specify a projection direction; higher-order moment-based image projection means for determining a pixel value at a point of intersection of a projection axis and a projection plane based on:

$$25 \quad P = \left[ \left( \sum_{i=1}^n Vi / n \right)^r - \sum_{i=1}^n (Vi / n)^r \right]^{1/r},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $Vi$ , and a real number greater than one is denoted by  $r$ ; and projection image display means for displaying a projection

image.

According to the image processing apparatus of the ninth aspect, the higher-order moment-based image projection method of the first aspect can be suitably implemented.

- 5 In a tenth aspect, the present invention provides an image processing apparatus characterized in comprising: three-dimensional data storage means for storing three-dimensional data; projection direction specifying means for use by an operator to specify a projection direction; higher-order moment-based image projection means for determining a pixel value  $G$  at a point of intersection of a  
10 projection axis and a projection plane as:

$$G = \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i / n)^r \right|^{1/r},$$

- where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ ; and projection image display means for displaying a projection  
15 image.

According to the image processing apparatus of the tenth aspect, the higher-order moment-based image projection method of the second aspect can be suitably implemented.

- In an eleventh aspect, the present invention provides an image processing  
20 apparatus characterized in comprising: three-dimensional data storage means for storing three-dimensional data; projection direction specifying means for use by an operator to specify a projection direction; higher-order moment-based image projection means for determining a pixel value  $G$  at a point of intersection of a projection axis and a projection plane as:

$$25 \quad G = \exp \left\{ \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i / n)^r \right|^{1/r} \right\},$$

where the number of three-dimensional data values along said projection axis is

denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ ; and projection image display means for displaying a projection image.

According to the image processing apparatus of the eleventh aspect, the higher-order moment-based image projection method of the third aspect can be suitably implemented.

In a twelfth aspect, the present invention provides an image processing apparatus characterized in comprising: three-dimensional data storage means for storing three-dimensional data; projection direction specifying means for use by an operator to specify a projection direction; higher-order moment-based image projection means for determining a pixel value at a point of intersection of a projection axis and a projection plane based on:

$$P = \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i^r) / n \right|^{1/r},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ ; and projection image display means for displaying a projection image.

According to the image processing apparatus of the twelfth aspect, the higher-order moment-based image projection method of the fourth aspect can be suitably implemented.

In a thirteenth aspect, the present invention provides an image processing apparatus characterized in comprising: three-dimensional data storage means for storing three-dimensional data; projection direction specifying means for use by an operator to specify a projection direction; higher-order moment-based image projection means for determining a pixel value  $G$  at a point of intersection of a projection axis and a projection plane as:

$$G = \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i^r) / n \right|^{1/r},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ ; and projection image display means for displaying a projection  
5 image.

According to the image processing apparatus of the thirteenth aspect, the higher-order moment-based image projection method of the fifth aspect can be suitably implemented.

In a fourteenth aspect, the present invention provides an image processing  
10 apparatus characterized in comprising: three-dimensional data storage means for storing three-dimensional data; projection direction specifying means for use by an operator to specify a projection direction; higher-order moment-based image projection means for determining a pixel value  $G$  at a point of intersection of a projection axis and a projection plane as:

$$15 \quad G = \exp \left\{ \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i^r) / n \right|^{1/r} \right\},$$

where the number of three-dimensional data values along said projection axis is denoted by  $n$ , a data value is denoted by  $V_i$ , and a real number greater than one is denoted by  $r$ ; and projection image display means for displaying a projection  
image.

20 According to the image processing apparatus of the fourteenth aspect, the higher-order moment-based image projection method of the sixth aspect can be suitably implemented.

In a fifteenth aspect, the present invention provides the image processing apparatus having the aforementioned configuration, characterized in that:  $2 \leq r \leq$   
25 128.

According to the image processing apparatus of the fifteenth aspect, the



higher-order moment-based image projection method of the seventh aspect can be suitably implemented.

In a sixteenth aspect, the present invention provides the image processing apparatus having the aforementioned configuration, characterized in comprising:  
5 order specifying means for use by the operator to specify  $r$ .

According to the image processing apparatus of the sixteenth aspect, the higher-order moment-based image projection method of the eighth aspect can be suitably implemented.

According to the higher-order moment-based image projection method and  
10 the image processing apparatus of the present invention, all data values along a projection axis are incorporated in a projection image produced from three-dimensional data.

Further objects and advantages of the present invention will be apparent from the following description of the preferred embodiments of the invention as  
15 illustration in the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a configuration diagram of a medical image diagnostic apparatus in accordance with the present invention.

20 Figure 2 is an exterior view of a slide lever operated by an operator to change the order  $r$ .

Figure 3 is a flow chart showing higher-order moment-based image projection processing in accordance with the first embodiment.

Figure 4 is an explanatory diagram two-dimensionally showing exemplary  
25 numeric values for a higher-order moment-based image projection calculation.

Figure 5 is another explanatory diagram two-dimensionally showing exemplary numeric values for the higher-order moment-based image projection calculation.

Figure 6 is an explanatory diagram two-dimensionally showing exemplary  
30 numeric values for an image projection calculation employing a maximum

intensity projection method.

Figure 7 is another explanatory diagram two-dimensionally showing exemplary numeric values for the image projection calculation employing the maximum intensity projection method.

5        Figure 8 is a flow chart showing higher-order moment-based image projection processing in accordance with a third embodiment.

#### DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will now be described.

##### 10    - First Embodiment -

Figure 1 is a configuration diagram of a medical image diagnostic apparatus in accordance with a first embodiment.

The medical image diagnostic apparatus 100 comprises an imaging apparatus 1 and an image processing apparatus 2.

15        The imaging apparatus 1 is an X-ray CT, MRI or ultrasonic diagnostic apparatus, for example, that images a subject K and passes acquired data to the image processing apparatus 2.

The image processing apparatus 2 comprises a three-dimensional data constructing/storing section 2a for constructing three-dimensional data based on  
20    the data passed from the imaging apparatus 1 and storing the three-dimensional data, a projection direction specifying section 2b for use by an operator to specify a projection direction, an order specifying section 2c for use by the operator to specify an order  $r$ , a projection calculating section 2d for performing a higher-order moment-based image projection calculation, and a projection image  
25    display section 2e for displaying a projection image on a display screen.

Figure 2 is an external view of a slide lever operated by the operator to change the order  $r$ .

By moving the slide lever, the order  $r$  can be varied between 2 and 128.

Figure 3 is a flow chart showing the higher-order moment-based image  
30    projection processing in the image processing apparatus 2.

At Step ST1, the three-dimensional data constructing/storing section 2a constructs three-dimensional data based on data passed from the imaging apparatus 1, and stores the three-dimensional data.

At Step ST2, the projection direction specifying section 2b reads a  
5 projection direction from a device (e.g., a trackball) operated by the operator to specify a projection direction.

At Step ST3, the projection calculating section 2d defines a projection plane perpendicular to the projection direction.

At Step ST4, the projection calculating section 2d takes one pixel on the  
10 projection plane as a pixel of interest.

At Step ST5,  $n$  data values  $V_i$  along the projection axis corresponding to the pixel of interest are taken out from the three-dimensional data.

At Step ST6, the order specifying section 2c reads an order  $r$  from a device (e.g., the slide lever shown in Figure 2) operated by the operator to specify an  
15 order  $r$ .

At Step ST7, the projection calculating section 2d calculates a pixel value  $G$  according to the following equation:

$$G = \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i / n)^r \right|^{1/r}.$$

At Step ST8, the projection calculating section 2d repeats Steps ST4 — ST7  
20 until pixel values  $G$  for all pixels are obtained.

At Step ST9, the projection image display section 2e displays an obtained projection image on a display screen.

At Step ST10, if the operator issues a command to terminate the processing, the processing is terminated; otherwise, the flow goes back to Step ST2.

25 Figures 4 and 5 are explanatory diagrams two-dimensionally showing exemplary numeric values for the higher-order moment-based image projection calculation. The order  $r = 2$  is assumed.

Figure 4 shows pixel values of pixels A, B, C and D of a projection image

obtained by projecting three-dimensional data TD1 according to higher-order moment-based image projection. The projection axes a, b, c and d are projection axes corresponding to the pixels A, B, C and D, respectively.

Figure 5 shows pixel values of pixels A, B, C and D of a projection image  
5 obtained by projecting three-dimensional data TD2 according to higher-order moment-based image projection.

Figures 6 and 7 are explanatory diagrams two-dimensionally showing exemplary numeric values for an image projection calculation employing the maximum intensity projection method.

10 Figure 6 shows pixel values of pixels A, B, C and D of a projection image obtained by projecting the three-dimensional data TD1 according to image projection employing the maximum intensity projection method.

Figure 7 shows pixel values of pixels A, B, C and D of a projection image  
15 obtained by projecting the three-dimensional data TD2 according to image projection employing the maximum intensity projection method.

As can be seen by comparing Figures 4 and 5 in which a higher-order moment is employed, data values other than the maximum along a projection axis are incorporated in the projection image (for example, the pixel values are different depending on whether the minimum along the projection axis is 10 or 0).  
20 On the other hand, as can be seen by comparing Figures 6 and 7 in which the maximum intensity projection method is employed, data values other than the maximum along a projection axis are not incorporated at all on the projection image (for example, the pixel values are equal to the maximum, 70, regardless of whether the minimum along the projection axis is 10 or 0).

25 This means that, for example, whether only a bone or both a bone and overlying blood vessel are present in the projection direction cannot be discerned on a projection image according to the maximum intensity projection method, but can be discerned on a projection image according to the present invention.

Moreover, as can be seen by comparing Figures 4 and 6, information on  
30 whether the data has only one maximum point or a plurality of maximum points

is incorporated in the projection image in Figure 4 in which a higher moment is employed (i.e., the pixel values are different depending on the number of the maximums, 70, along the projection axis). On the other hand, in Figure 6 in which the maximum intensity projection method is employed, information on whether the data has only one maximum point or a plurality of maximum points is not incorporated at all on the projection image (i.e., the pixel value is 70 regardless of the number of the maximums, 70, along the projection axis).

The same can be seen by comparing Figures 5 and 7.

This means that, for example, whether only one bone or a plurality of overlying bones are present in the projection direction cannot be discerned on a projection image according to the maximum intensity projection method, but can be discerned on a projection image according to the present invention.

#### - Second Embodiment -

At Step ST7 of Figure 3, the projection calculating section 2d may calculate the pixel value G according to the following equation:

$$G = \exp \left\{ \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i / n)^r \right|^{1/r} \right\}.$$

This pixel value G enables all data values along the projection axis to be incorporated in the projection image.

#### - Third Embodiment -

Figure 8 is a flow chart showing the higher-order moment-based image projection processing in the image processing apparatus 2. The flow chart is the same as that in Figure 3 except that Step ST7 in Figure 3 is changed to Step ST7'. Thus, only Step ST7' will be explained below.

At Step ST7', the projection calculating section 2d calculates the pixel value G according to the following equation:

$$G = \left| \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i^r) / n \right|^{1/r}.$$

This pixel value G also enables all data values along the projection axis to be incorporated in the projection image, and sometimes gives a better result than the first embodiment.

**- Fourth Embodiment -**

- 5           At Step ST7' in Figure 8, the projection calculating section 2d may calculate the pixel value G according to the following equation:

$$G = \exp \left\{ \left[ \left( \sum_{i=1}^n V_i / n \right)^r - \sum_{i=1}^n (V_i^r) / n \right]^{1/r} \right\},$$

- 10           This pixel value G also enables all data values along the projection axis to be incorporated in the projection image, and sometimes gives a better result than the second embodiment.

Any one of the pixel values G obtained in the first — fourth embodiments and other functions G(P) may be appropriately selected according to the purpose of producing the image, or preference.

- 15           Many widely different embodiments of the invention may be configured without departing from the spirit and the scope of the invention. It should be understood that the present invention is not limited to the specific embodiments described in the specification, except as defined in the appended claims.